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THESIS

SEARCHING FOR EFFECTIVE TRAINING SOLUTIONS FOR FIREFIGHTING: THE ANALYSIS OF EMERGENCY RESPONSES AND LINE OF DUTY DEATH REPORTS FOR LOW FREQUENCY, HIGH RISK EVENTS

by

Deanna M. McDevitt

September 2017

Thesis Advisor: Amela Sadagic
Second Reader: Glen Woodbury

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Since 9/11, the fire service has experienced a shift and an expansion in the nature of threats and hazards that it faces. Despite advances in the field, firefighters are still losing their lives inside of burning buildings, and they must find new ways of identifying training gaps and improving current training practices. This thesis explores whether emergency incidents connected to low frequency and high risk events contain sufficient warning signs or indicators of imminent catastrophic events, if firefighters could identify them, and if there was a potential of changing decision making and averting a tragedy. In order to create a firm basis for this discovery, this research effort included a detailed analysis of the National Institute for Occupational Safety and Health's line of duty death reports from the years 2013–2015. The work provided an opportunity to learn from past events and practices and identify successes and failures in the firefighting domain without the bias of being closely involved with the cases or having a specific agenda. Quantitative analysis performed on this data set and the knowledge gleaned from looking at the events after the fact provide a foundation for advising novel training approaches and scenarios that can be used to train both individuals and teams of fire fighters.

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SEARCHING FOR EFFECTIVE TRAINING SOLUTIONS FOR FIREFIGHTING: THE ANALYSIS OF EMERGENCY RESPONSES AND LINE OF DUTY DEATH REPORTS FOR LOW FREQUENCY, HIGH RISK EVENTS

Deanna M. McDevitt
Captain, Boston Fire Department
B.A., Yale University, 2003

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September 2017

Approved by: Amela Sadagic, Ph.D.
Thesis Advisor

Glen Woodbury
Second Reader

Erik Dahl
Associate Chair for Instruction
Department of National Security Affairs

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ABSTRACT

Since 9/11, the fire service has experienced a shift and an expansion in the nature of threats and hazards that it faces. Despite advances in the field, firefighters are still losing their lives inside of burning buildings, and they must find new ways of identifying training gaps and improving current training practices. This thesis explores whether emergency incidents connected to low frequency and high risk events contain sufficient warning signs or indicators of imminent catastrophic events, if firefighters could identify them, and if there was a potential of changing decision making and averting a tragedy. In order to create a firm basis for this discovery, this research effort included a detailed analysis of the National Institute for Occupational Safety and Health's line of duty death reports from the years 2013–2015. The work provided an opportunity to learn from past events and practices and identify successes and failures in the firefighting domain without the bias of being closely involved with the cases or having a specific agenda. Quantitative analysis performed on this data set and the knowledge gleaned from looking at the events after the fact provide a foundation for advising novel training approaches and scenarios that can be used to train both individuals and teams of fire fighters.

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LIST OF ACRONYMS AND ABBREVIATIONS

AR	Augmented Reality
BFD	Boston Fire Department
CDC	Centers for Disease Control and Prevention
CFD	computational fluid dynamics
EMS	emergency medical services
FDNY	Fire Department of New York
FOV	field of view
HMD	Head-Mounted Display
IFSTA	International Fire Service Training Associations
IST	Institute for Simulation and Training
LODD	Line of Duty Death
MOVES	Modeling, Virtual Environments and Simulation
NCS4	National Center for Spectator Sport Safety and Security
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute for Science and Technology
UL	Underwriters Laboratory Inc.
VR	Virtual Reality

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EXECUTIVE SUMMARY

Research in the firefighting domain points to the fact that fires are becoming more dangerous; hazards on the fire ground have evolved and become more deadly over the years.[1] Underwriters Laboratory Inc. (UL), an organization that conducts product safety testing and certification, has identified some of the changing threats and hazards to firefighters in the field.[2] The changing nature of fire service response and faster spreading fire behavior signals a need for specific training programs and solutions that harness virtual reality and computer-supported simulations.

This thesis focuses on Firefighter Line of Duty Death (LODD) Reports published by The National Institute for Occupational Safety and Health (NIOSH). The central attention of these LODD reports is on incidents that are low frequency and high risk events; examples of those events are fire-related situations, hazardous material incidents, cases of collapse, and special technical response scenarios. Indicators and warning signs identified in those reports originate from actual events where firefighters lost their lives; the same indicators are used as a guidance to advise the use of alternative training solutions, specifically Virtual Reality (VR) solutions. VR solutions have proven themselves as powerful tools in a number of other domains where they were used to save resources and conduct training on situations that could not be supported using traditional training approaches.

One of the questions addressed in this research is: Do the LODD events show sufficient warning signs or indicators that can change decision making and avert a tragedy? Data analysis conducted in this thesis included data from reports from three years: 2013, 2014 and 2015. A total of 57 reports were analyzed with a total number of line of duty deaths being 62. The highest number of deaths reported was a result of cardiovascular disease (CD) and myocardial infarction (MI), the majority of them caused

[1] "Modern Residential Fires," Underwriters Laboratory, http://newscience.ul.com/articles/modern-residential-fires, accessed August 10, 2015.

[2] "House fire furnishing comparison," YouTube video, 3:57, posted by "UL firefighter safety," June 19, 2013, https://www.youtube.com/watch?v=4caM9dZwGL0, accessed November 22, 2015.

by the condition of physical exertion leading to a cardiac event (PEC). "CD only" caused 14 deaths (22.58% of all deaths); 12 of these were older than 40 years. "MI only" caused 12 deaths (19.35% of all deaths); 10 of these were older than 40 years. Some of these reports included causes of death that had several named causes contributing to the loss (combined effect). For example, Cardiovascular Disease was paired with myocardial infarction (MI) and diabetes mellitus (DB). Aortic dissection and myocarditis were other underlying medical conditions leading to death.

The NIOSH reports were examined for the *condition under which death occurred* and the findings from the *causes of death* were repeated. The common thread throughout reports that were analyzed for this thesis was the fact that a single factor - physical exertion led to the cardiac event—*caused* the line of duty death (31 deaths); one additional death was caused by a combination of physical exertion leading to a cardiac event and smoke inhalation. The next leading *causes of death* were victim of collapse (8 deaths), smoke inhalation (3 deaths), falls (3 deaths) and sudden cardiac death (2 deaths). Becoming trapped, having motor vehicle accidents and water rescue caused 1 death each.

The *duties* being performed while these deaths occurred varied and did not appear to have significant connection to the causes of death. However, what the data did show is that advancing a line in the interior of a building caused the most number of deaths: advancing the interior line was a duty in 14 cases of death, and search and rescue was the second most hazardous duty in seven of the death reports. Surprisingly, seven deaths occurred during training exercises. Other types of duties where firefighters lost their lives included while investigating incidents (4), driving an apparatus (2), conducting emergency medical services (1), and performing technical rescue (1).

Analysis was also conducted for *indicators* surrounding the circumstances of the death. "Underlying medical conditions" were named as the sole indicator in 28 deaths. In the rest of the reports where indicators were named, there were a number of indicators from two to up to nine that could have signaled warning of an impending tragedy. In 12 of the cases, an unreported hazard was a major factor in the line of duty death. In many of these cases, firefighters recognized a hazard but did not report to the incident commander so that the remaining members on the fireground would be made aware of the danger.

Crew integrity was another common *indicator*. In seven of the cases, members were separated from each other and a lack of accountability led to a line of duty death.

It is interesting that in 25 cases of firefighters' deaths, a wide variety of indicators as well as combination of several indicators were listed. Although no specific pattern emerged, the indicators named in the analysis and the variety of ways they combined to create a deadly situation provide valuable information that helps design innovative training scenarios. From the more common problems of pre-existing hazardous structures to the rare events of temperature inversion creating a dangerous environment, each report gave valuable information for indicators that firefighters can and should become familiar with.

Reports also included *recommendations* on how to address the situation and avoid those cases in the future. In 20 of the cases, situational awareness was named as a key recommendation. This was often paired with an accountability system, size up, and conducting an adequate risk assessment for decision making. Other recommendations that could be incorporated into training scenarios included air management, deployment to the Charlie side (back of the building), dispatch communications, collapse awareness, modern fire behavior, Mayday training, and an increased knowledge of fires involving wind conditions.

The analysis of data that were derived from NIOSH reports provides us with a basis for a range of recommendations and suggestions on how to address factors that led to catastrophic events—the deaths of firefighters. In cases where physical exertion led to a cardiac event, the departments should develop annual medical evaluation and annual physical ability evaluations for their members. A preventative wellness and fitness program for all members has the potential to decrease these line of duty deaths. Exercise stress tests and ensuring that injured members are cleared for duty before returning to work are strongly recommended measures suggested by the committees conducting the NIOSH investigations.

A training program designed around the indicators from the NIOSH reports has a potential of increasing situational awareness and improving firefighter ability to identify

and avert line of duty deaths and injuries. Simulation and virtual reality training solutions would provide the opportunity for building a different kind of education, one that can provide opportunity for repetitive training and help build recognition-primed decision-making skills of firefighters. This type of real-time, scenario-driven training systems will represent education that is different from traditional classroom approach; it will be safer than live-fire while giving firefighters the opportunity to build their skills and increase their experiences. In some cases, VR simulations and simulators may prove to be the only way to train safely. Those systems also provide an option for situations when access to training may be prohibited or limited. For example, new firefighters who are not yet ready to be out in the hostile environment or at the other extreme, in cases of radiation, training solutions that simulate those extreme conditions present the only safe way to train.

There is a variety of reasons why training solutions that harness VR technology have been endorsed and used in a number of domains like military domain, training of medical personnel and industry. A major reason to rely on VR has been in its potential to save resources, providing an alternative environment for practice. Resources that could be saved include staffing, organizing, logistics, transporting, fuel, maintenance, parts, etc. VR can also provide training when there are no other options available. Any domain could be scrutinized to identify the things and situations that could not be supported otherwise. In some cases, it would even focus on the need to run through a large number of training scenarios in short period of time. To do that effectively, it would be necessary to establish a training regimen and a model for decision-making practice, and create challenging training scenarios that will support that practice.

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I. INTRODUCTION

The Fire Service is on the front lines, protecting neighborhoods and creating a level of emergency preparedness that helps ensure our homeland is safe, secure, and resilient against a variety of hazards. Fire departments across the country respond to a wide range of incidents including medical calls, motor vehicle accidents, elevator accidents, fires, gas leaks, water leaks, technical rescues, explosions, hazardous material incidents, terrorism, mass casualty incidents, and to anything else that involves a call to 911. It can be argued that the Fire Department has expanded its mission to include an all-hazard response.[1] Yet, when the alarm sounds, firefighters must be trained, prepared, and equipped to mitigate and recover from whatever the emergency situation may be.

The driving factor for this thesis is to provide a contribution towards effective and creative avenues for training programs for the Fire Service in this post 9/11 world. Specifically, firefighters across the Nation can benefit from an increased focus on training for low-frequency and high-risk events. Effective training programs will improve the decision-making skills of its members, improving upon each member's experience and training in a variety of situations while producing quick results, saving resources, and keeping firefighters as safe as possible.

A. PROBLEM STATEMENT

The premise of this thesis is that today's firefighters must find ways to improve their training. This is especially true for the hazards associated with emergency responses that fall in the category of low frequency events that also pose a high risk to responders, civilians, and the environment.

The Recognition-Prime Decision-making model has demonstrated that individuals rely on past experiences and memory markers for decision making in situations where

[1] Rosemary Cloud, "Future Role of Fire Service in Homeland Security" (Master's thesis, Naval Postgraduate School, 2008).

they are required to make rapid decisions.[2] When first responders are faced with events that rarely occur, they may lack these past experiences that will help them make good decisions. An effective and well-designed training program is a possible solution that could fill in the gap for developing recognition-primed decision-making skills for these low frequency and high-risk incidents.

In the years since the devastating events that occurred on 9/11, the fire service has experienced a shift and an expansion in the nature of threats and hazards that they face. Both the threats have changed and the role of the department to address these threats has changed.[3] Despite the fact that equipment and technology have advanced to include fully encapsulating gear, expensive pumping technology for fire apparatus, enhanced communications, and new materials for extinguishment, firefighters are still losing their lives inside of burning buildings.[4]

In 1977, The National Fire Protection Association (NFPA) began identifying and summarizing all on-duty deaths[5] in the fire service for the preceding year.[6] Since the institution of this tracking system, the number of firefighter fatalities has dropped by nearly 2/3^rds^. However, there has also been a drop in the number of structure fires during this same period.[7] Since 1977, the number of structure fires each year has declined by 52 percent.[8] The question is asked whether the decrease in fire fatalities is due to increases

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[2] Gary A Klein, *A recognition-primed decision (RPD) model of rapid decision making*. (New York: Ablex Publishing Corporation, 1993), 139–147.

[3] U.S. Congress, Senate, Committee on Appropriations, Subcommittee on VA-HUD-Independent Agencies, *Needs of America's firefighters: hearing before a subcommittee of the Committee on Appropriations, United States Senate*, 107th Cong., 2nd sess, special hearing, February 5, 2002, Washington, DC. Washington: U.S. G.P.O, https://www.gpo.gov/fdsys/pkg/CHRG-107shrg86401/pdf/CHRG-107shrg86401.pdf, accessed September 2,2016.

[4] Rita F. Fahy, Paul R. LeBlanc, and Joseph L. Molis, "What's changed over the past 30 years?," *National Fire Protection Association* (2007): 1–15.

[5] NFPA tracks data on these United States firefighter fatalities (USFF) that occur at the scene of any alarm (fire or non-fire), while responding to or returning from an alarm, or while performing other duties such as training, maintenance, public education, inspection, and investigation.

[6] Fahy, LeBlanc, Molis, "What's changed over the past 30 years?," 1–15.

[7] Rita F. Fahy, Paul R. LeBlanc, and Joseph L. Molis, " Firefighter Fatalities in the United States -- 2009,"*National Fire Protection Association*, Quincy MA, (July 2010).

[8] Rita F. Fahy, "US Fire Service fatalities in structure fires, 1977–2009," *National Fire Protection Association*, Quincy MA, (2002): 1–9.

in protective equipment, fire-ground procedures and training or instead due to the fact that there is an overall decrease in fires nationwide. Researchers also ask if firefighters are as likely to die in structure fires today as they would have been 25 or 30 years ago?

Rita Fahy, Paul LeBlanc, and Joseph Molis write papers and articles for the National Fire Protection Association and claim that the RATE of firefighter deaths insides building has not fallen according to the comparative decline in fires and believe a firefighter is more likely to be killed inside a structure fire today than he/she would have been 30 years ago.[9] Most notable in their research is the significant increase in the rate of death of firefighters due to traumatic injuries while operating inside structures, including smoke inhalation, burns, and crushing or internal injuries.

The above statistics are extremely concerning. Why are firefighters continuing to die inside structures? Hazards on the fire ground have evolved and become more deadly over the years.[10] Underwriters Laboratory Inc. (UL), a product safety testing and certification organization, has identified some of the changing threats and hazards to firefighters in the field; their most recent research points to the fact that fires are becoming more dangerous.[11]

Some experts say that the scope of a response required for training purposes has increased[12] and others claim that the fire service has failed to keep up with preparing for the variety of hazards.[13] The problem of firefighters dying in the line of duty is a complex problem and likely a compilation of a variety of factors: lack of experience, the wide variety of hazards, inadequate training, lack of opportunity for “on the job” training, attrition rates, and fire service culture—to name a few. New members do not have the experience or a good base of “on the job” training. Consequently, they may not be

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[9] Fahy, LeBlanc,, Molis, “ Firefighter Fatalities in the United States – 2009.”

[10] Underwriters Laboratory, “Modern Residential Fires.”

[11] Underwriters Laboratory, “House fire furnishing comparison.”

[12] Douglas Weeks, “Strategic Changes for the Fire Service in the Post 9/11 Era” (Master’s thesis, Naval Postgraduate School, 2007).

[13] Douglas Paton, “Disaster relief work: An assessment of training effectiveness,” *Journal of Traumatic Stress* 7, no. 2 (February, 2006): 275–288, accessed December 20,2015, doi 10.1002/jts.2490070208.

prepared for the incidents they respond to. At the same time, there is opportunity to change the way we train when members are new to the department and eager to learn.

Perhaps the decrease in the number of fires over the years has led to a sense of complacency that has severely inhibited preparedness. The suggested increase in the rate of firefighters who have lost their lives inside burning buildings points to the need to design and implement an improved training program. This program must grab the attention of its young members and help motivate and prepare them for the changing nature of the job.

Looking at this problem from a different perspective, perhaps firefighters are prepared for the variety of problems in the field but they do not have the capability to react in the moment and respond appropriately. The hazards and threats associated with emergency responses are possibly too vast and changing too quickly for emergency responders to keep up with the pace and train appropriately. Finally, firefighters could be trained for the response but the lack of opportunity to practice under pressure and with time constraints may contribute to poor decision making in actual events.

Research has shown that recognition-primed decisions are based on an individual's past experiences in a similar situation. Richard Gasaway, author of the book, "Situational Awareness for Emergency Responders," describes how incidents that one does not see very often are the situations when one's life and safety can be most jeopardized. How can firefighters gain the experience necessary for quality recognition-primed decisions if the incidents involving these types of decisions occur so infrequently?[14] These issues present serious problems for firefighters training for low frequency, high-risk events.

The complexity of demands presented in the current operational environment suggests that training must become a top priority. It is therefore imperative that departments invest maximum effort to focus on improving the preparedness of their members. The variety of risks, hazards, and threats facing the current fire service demand

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[14] Richard B. Gasaway, *Situational Awareness for Emergency Response* (Oklahoma: PennWell Corporation, 2013), 311.

that. Vincent Doherty, a Retired Captain with the Fire Department of New York (FDNY), wrote in his thesis that Fire Departments must expand and improve their skills for responding to all hazard incidents and calls for the Fire Service to adopt conceptual changes from training evolutions.[15]

The changing nature of fire service response and faster spreading fire behavior signals a need for specific training programs that include programs that harness virtual reality and computer-supported simulations. There are situations in the fire service that firefighters do not see very often and consequently, may not be prepared to make quick and effective decisions under time constraints. Innovative training programs could provide part of the solution. Individual firefighters need to have the opportunity to develop memory markers for decision making in emergency situations. The questions that need to be answered are how the firefighters can prepare for scenarios that they don't see very often?

A number of sources have explored the changing nature to the fire service, in particular, the increase in hazards of modern building construction, the growth in the rate of fire spread due to modern furnishings, the possibility of terrorist attacks, and the number of hazardous material incidents that are low frequency but high-risk events. However, few research efforts have tackled the way in which the fire service members can become experts in their field for these dangerous events.

The gap in the research is in the lack of understanding about tested, effective training solutions capable of preparing firefighters for these ever-changing threats. The problem space is the knowledge gap when considering the low frequency and high-risk scenarios in the fire service. The academic knowledge gap is in the lack of training solutions for such incidents. Virtual reality (VR) and other technologies integrated in computer-supported simulations have a potential to generate significant benefits to fire service training. These solutions are a perfect match to provide much needed experiences for low-frequency high-risk events, in a cost-effective and safe manner.

[15] Vincent Doherty, "Metrics for Success: Using Metrics in Exercises to Assess the Preparedness of the Fire Service in Homeland Security" (Master's thesis, Naval Postgraduate School, 2004).

B. RESEARCH QUESTIONS

The research question central to this thesis is this one - During an emergency response to an environment that is immediately dangerous to the life and health of responders, are sufficient warning signs or indicators of imminent catastrophic events present and identifiable to the firefighters and could they (if addressed properly) have a potential to change decision making and avert a tragedy?

An investigation is made to identify training deficiencies that may have existed in cases of low-frequency, high-risk events that, together with other factors, contributed to the line of duty death. The identified training gaps i.e., skills that may have been lacking, will be considered as candidates for alternative (and additional) training sessions that would use computer-based simulations. Close attention will be kept on the issue of experiences with training simulations being adequate replacements and substitutes for experiences in traditional (live fire) training solutions.

Visual simulations have been proven to be an effective training solution in many application domains that share common characteristics with firefighting, and it is possible to suggest that simulations could be used in this domain as well. Additionally, the argument can be made that training using simulations has a potential to be more cost-effective training option (it saves resources), and it can also be used to enable training practices that could not be possible otherwise. Examples include situations with real fire, explosive materials and with a number of civilians being a part of the scenario.

If the assumption is that additional training can address a lack of experience, how should fire departments design training to accomplish this? Some training situations can be supported by using virtual reality (VR) and some using augmented reality (AR)—the type of training is dependent on the skill set that one is interested in, the type of interactions and system responses that a trainee needs to have in such computer supported training environment. In the case of AR and VR, a number of ongoing research efforts are invested to study if those types of training are effective and beneficial within the overall training regimen, how good the simulations are, how good they can be, and

finally if the skills and knowledge acquired in particular training sessions with simulation will make the leap into real life experience.

C. SCOPE OF THESIS

The scope of this thesis is to examine data sets and information that have been made available in Firefighter Line of Duty Death (LODD) Reports published by The National Institute for Occupational Safety and Health (NIOSH). The focus of these LODD reports is on incidents that are low-frequency and high-risk events (for example, fire-related situations, hazardous material incidents, cases of collapse, and special technical response scenarios). Using NIOSH reports can present limited information as the researcher has not personally designed the data collection, conducted investigations and interviews to guarantee unbiased findings; however, the availability and consistency of NIOSH reports for LODD suggest that those are nevertheless a very valuable tool for analysis and discovery.

Indicators and warning signs from actual events where firefighters lost their lives can be used to present training solutions, specifically VR solutions. Those training solutions have proven themselves as powerful tools with a potential of saving resources and conducting training on situations that we could not otherwise do. This includes helping to motivate learning and training. For example, a classroom lecture often considered as not motivating to students, especially for adult learners, while sensory based and hands-on operational learning is far more captivating, engaging, and effective.[16]

D. RESEARCH DESIGN

The work on this thesis includes a study of the firefighting profession in the United States, specifically types of responses and skills needed to be proficient in the job. One of the goals is to find out how firefighting has changed over time and discover the best ways for urban departments to train for the variety of hazards and risks they will

[16] James Robbins Kidd, *How adults learn*. (University of Michigan: Association Press, 1973).

face. The purpose of this research is to help understand how to address the gaps in existing training programs.

In order to discover what needs to be taught in these training programs, the work will include a detailed analysis of NIOSH reports. The main objective is to discover if there were indicators that may have been consistently missed in events where firefighters lost their lives in the line of duty. Do the events show sufficient warning signs that can change decision making and avert a tragedy? A secondary question is whether or not the awareness and a training program designed around these indicators have a potential of assisting the firefighters in identifying and preventing line of duty deaths and injuries.

Additionally, an investigation will be made to identify the most effective way of providing training experiences using computer simulations, and whether or not this training has a potential of substituting the actual experience. If the assumption is that training can substitute for lack of experience, how should fire departments design training to accomplish this?

In the case of training solutions that use VR and AR, is this training adequate and sufficient for the training gap identified in the study of NIOSH reports? How good are the simulations and how good can they be? What types of transfer of training results and experiences has been identified by researchers? Did the simulation enable training forces to make successful transition and leap into real life experience?

A basis for analysis of NIOSH reports will be a data set with selected parameters that are of interest in our study. This set will be created from a select group of line of death reports where the reported deaths of fire fighters directly resulted from low-frequency and high-risk events. A spreadsheet used to encode this information will have information about the number of firefighters' deaths reported in each event, cause of the fire, age of each firefighter, their time on the job, training they had, to name just a few.

Data set from a large number of NIOSH reports will allow us to identify trends along each parameter that has been recorded. For example, we may find that firefighters who have died had similar time on the job—it may happen that a majority of the deaths occurred when firefighters had between five and ten years on the job, which could

suggest that they may have been overly confident in their decision making yet lacked a sufficient experience and memory markers to escape a dangerous situation.

A subset of NIOSH reports that will be treated in this study will be chosen based on the incidents that caused the firefighters' deaths. Focus of our attention will be on situations where firefighters were inside the buildings: they were the victims of burning structure collapse, death caused by extreme fire behavior as well as firefighters being trapped, lost, disoriented, and running out of air. Reports from the last three years will be included in the analysis, focusing specifically on line of duty deaths inside buildings.

This thesis presents the opportunity to learn from past events and practices, the successes and failures in firefighting domain without the bias of being closely involved with the cases or having a specific agenda. This quantitative analysis and the knowledge gleaned from looking at the events after the fact will provide a foundation for advising novel scenarios that could be used to train both individual fire fighters and teams on a daily basis. Application for improved and more effective training will include critical review of indicators gleaned from the data.

An important aspect of this thesis is to analyze and discuss if a particular training program could be framed and how the simulations could be an integral part of that program. Could an increased awareness and a training program designed around indicators from the NIOSH reports assist firefighters in identifying and averting line of duty deaths and injuries?

In order to address these questions, a feasibility analysis will be conducted for the project. The indicators identified in the study will be used to project training needs and scenarios. The analysis will include consideration of training being realistic enough, and if it would be possible to train the volume of firefighters currently in existence in an urban fire department.

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II. LITERATURE REVIEW

Review of the literature was divided into four categories: fire behavior, decision making for low-frequency and high-risk events, training programs for emergency responders, and virtual reality and simulation programs.

Studies have shown the instances where fire is spreading faster and situations becoming more dangerous in smaller operational timeframes than in the past. There is an understanding that the situations that cause the biggest problems are the incidents that include high-risk situations seldom experienced by the firefighters who therefore have very few opportunities to train and improve their decision-making skills.

The importance of training is a focal point of this thesis. Literature review reinforces our understanding that the training domain lacks many solutions outside live fire experiences. Information included in this review covers the basic understandings about simulations: it explains different types of simulation and technology and explores articles that focus on when and where those training solutions are useful.

A. MODERN FIRE BEHAVIOR

The dangers of the job of firefighting have changed and evolved over the past 10 to 30 years. Scientists from Underwriters Laboratory Inc. (UL) and National Institute of Standards and Technology (NIST) lead the research into these changes, and produced highly useful understandings to the fire service on how fires have been changing.[17] Their researchers compared the contents of present day homes to “legacy” homes from the 1950s to 1970s and coined the term “modern fire behavior” to define the rapid speed and intensity of modern day fires.

The researchers suggest that these changes are due to a number of factors including the cumulative effect of larger homes, open house geometries, synthetic materials, and modern construction practices.[18] This research is ongoing as scientists

[17] Underwriters Laboratory, “House fire furnishing comparison.”

[18] Underwriters Laboratory, “Modern Residential Fires.”

have been conducting additional studies and gathering data to better understand the nature of fire. UL and NIST research demonstrates that firefighters can no longer rely on past practices and traditional tactics of previous generations to inform their knowledge of fire behavior and decision making on the fire-ground.[19]

Another line of research by Kerber et al., has been conducted with the goal of examining the hazards of residential flooring systems; the purpose of that work was to increase firefighters' knowledge of these systems.[20] The results and subsequent report contributed to improved understanding of decision making on the fire ground. The limits of this study are that it focused only on floor systems; however, the recommendations for tactical operations have been backed by their research data.

An analysis of the changing residential fire dynamics shows how operational timeframes have decreased, pointing to the need for more effective training programs. Steve Kerber analyzed the changing residential fire dynamics and its implications on operational timeframes; he demonstrated the increasing hazards to firefighters in shorter time periods.[21] This work points to the gap in training and experience of field Commanders as many of them are unaware of changing fire dynamics.

Literature that examines fire behavior focuses exclusively on the chemical and physical properties of fire, the fire tetrahedron, and the combustion process. In the text, Principles of Fire Behavior and Combustion, the authors Richard Gann and Raymond Friedman gave a comprehensive description of how fires start and spread; the goal was to inform fire fighters' decision-making.[22] The authors however lacked an in-depth

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[19] "Ibid.

[20] Steve Kerber, et al., "Improving Fire Safety by Understanding the Fire Performance of Engineered Floor Systems and Provide the Fire Service with information for Tactical Decision Making" Underwriters Laboratory, March 2012, accessed September 20, 2015, http://www.ul.com/global/documents/offerings/industries/buildingmaterials/fireservice/basementfires/2009%20NIST%20ARRA%20Compilation%20Report.pdf.

[21] Steve Kerber, "Analysis of Changing Residential Fire Dynamics and Its implications on Firefighter Operational Timeframes" Fire Technology (Nov 2011).

[22] Richard Gann & Raymond Friedman, *Principles of Fire Behavior and Combustion* (Burlington, MA: Jones and Bartlett Learning, LLC, 2013).

examination into "modern fire behavior" and the external factors that can influence the growth and behavior of fire.

A national requirement for firefighters upon entry into the fire service is completion of the National Fire Protection Association's (NFPA) Firefighter I & II courses (NFPA Standard 1001). In 102 hours of training for Firefighter I, only three hours are focused on fire behavior. For the 60 hours of Firefighter II, no portion of the training contains information on fire behavior. When firefighters are promoted to officers and made responsible for decision making on the fire ground, they receive no additional training on fire behavior.[23]

Another example of this gap in training for firefighters is found in the "International Fire Service Training Associations (IFSTA), Essentials of Firefighting Manual." This go-to guide for the fundamentals of firefighter training includes all requirements for the National Fire Protection Associations standards.[24] This guidebook is a reliable source for referencing the requirements for training and describing the variety of incidents firefighters respond to. Although it is titled the "Essentials of Firefighting," one can argue that there is missing material in the area of modern fire behavior, new construction methods, and hazards including terrorism, active shooters, and hazardous materials response.

B. LOW-FREQUENCY, HIGH-RISK EVENTS AND DECISION MAKING

In the fire service, decision making is a part of different event categories based on frequency and impact associated with those events. Frequency is defined by how often an incident occurs, and the impact (severity) is a measure of the consequences of an undesirable event. When departments are assessing risk and impact, training focuses on incidents or events that are low frequency and high risk/severity. The reason for the focus on low-frequency and high-risk incidents is that these incidents do not happen often, but

[23] "NIST and UL Research: Studying Fire Behavior and Fireground Tactics Part 1 and 2 – Workshop" Youtube video, 3:20:23, from a NIST and UL workshop, posted by International Association of Firefighters, August 25, 2013, http://youtu.be/TNI001YYYD4, accessed October 29, 2015.

[24] International Fire Service Training Association, *Essentials of Firefighting 5th Edition* (Oklahoma: Prentice Hall, 2008).

when they do occur, poor decisions can be made and people can be hurt or killed and property damaged.[25] High-frequency events are found to rarely cause problems because fire departments are trained and ready for these events through the use of standard operating procedures, proper strategy and tactics, operational risk management, and appropriate post incident analysis.[26]

Researcher Gordon Graham of Graham Research Consultants believes that mistakes are most likely to occur when we do things that we are not familiar with.[27] In a keynote speech at the National Center for Spectator Sport Safety and Security (NCS4) Conference, he states that in our personal and professional lives, we get very good at performing during high-frequency events because "things we do a lot, we tend to do very well." Decisions made for high-frequency tasks utilize a phenomenon called RPDM: Recognition Prime Decision-Making. Graham explains the theory by suggesting that the brain is a collection of past experiences. When a task is presented to an individual, he/she looks for a memory of a past incident that was similar. An individual will use his decision making that he/she used in the past because these decisions mitigated the emergency.

In his work Graham asserts that low-frequency and high-risk events are the problem in every occupation. If a situation is very risky and rarely encountered, an individual does not have memory slides of how to deal with these incidents. Graham outlines two kinds of high-risk and low-frequency events: discretionary timed tasks and core critical tasks.[28] He explains how individuals have time to think and make their decision in discretionary timed tasks. On the other hand, however, there is no time to think when deciding what to do for core critical tasks and these events rarely happen. To

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[25] National Institute For Occupational Safety and Health, "Career Lieutenant Dies After Being Trapped in the Attic After Falling Through a Roof While Conducting Ventilation – Texas," Centers for Disease Control and Prevention, June 27, 2012, http://www.cdc.gov/niosh/fire/reports/face201120.html, accessed November 16, 2015.

[26] Ibid.

[27] Gordon Graham, "Measure the Risk in High-Low Frequency Tasks" (keynote speech presented at the National Center for Spectator Sport Safety and Security Conference, New Orleans, Louisiana, August 2, 2012).

[28] Ibid.

perform adequately and safely on core critical tasks, it is necessary for firefighters to rely on memory markers developed from repetitive training.

C. TRAINING: YOU WILL OPERATE HOW YOU TRAIN

An article called "Lessons We Don't Learn: A study of the lessons of disasters, why we repeat them, and how we can learn from them" was published by Homeland Security Affairs. Authors Amy Donahue and Robert Tuohy explain how the rare occurrence of disasters makes it difficult for firefighters to prepare and train on the job.[29] Emergency responders use lessons learned as a way to learn from the past and improve future response; however, evidence suggests that mistakes are still repeated despite the lessons that should have been learned. The ability to capitalize on experience is ever more important because identifying lessons is one thing but a true learning is another matter. Homeland Security Practitioners are not learning from the past and demonstrating the need to drastically revamp training and exercise programs.[30]

Researchers examined data from 189 firefighter fatality investigations conducted by the National Institute of Occupational Safety and Health (NIOSH) between 2004 and 2009.[31] When NIOSH conducts their investigations, they give recommendations for preventing future firefighter injuries and deaths. In this study, researchers discovered the recommendations that were occurring most frequently in the reports and linked them to the contributing factors. The four major causes identified in this study were: under-resourcing, inadequate preparation for things going wrong during operations, incomplete adoption of incident command procedures and inadequate personnel readiness. For the purposes of this thesis research, the most important issue is the fact that members were not properly prepared for the emergency incidents. This points to a failure of training programs for both personnel preparedness and for operations as a company.

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[29] Amy Donahue and Robert V. Tuohy, *Lessons We Don't Learn: A Study from the Lessons of Disasters, Why We Repeat them, and How We Can Learn From Them*, Homeland Security Affairs 2, no. 2 (July 2006).

[30] Ibid.

[31] Kumar Kunadharaju, Todd D. Smith, David M. DeJoy. *Line-of-duty deaths among U.S. firefighters: An analysis of fatality investigations,* Accident Analysis & Prevention, 43, no. 3 (2001) 1171 – 1180.

D. VIRTUAL REALITY AND SIMULATION

Computer-supported simulation generates a dynamic representation of world phenomena that are of interest in a given application. For example, simulations can be used to represent weather changes, spread of fire, movement of a crowd in some space, and other similar events. In the training domain, simulation can replace and amplify real experiences and provide a trainee with the opportunity to be immersed in the scenario and interact with the virtual environment depicted in that simulation in real time.

Training simulations have been used in many domains, including the health professionals who needed to acquire and improve knowledge, skills, and attitudes while at the same time it protected the patients from unnecessary risks.[32] These type of training solutions can also be applied to the fire service and be used to enhance teamwork, retrain and practice fire ground scenarios as well as low-frequency and high-risk incidents. The limitations include a lack of some environmental factors and a potential for trainees to go through motions and fail to take full advantage of the training opportunity.

The Institute for Simulation and Training (IST), the University of Central Florida, the U.S. Army and the Orange County (Florida) Fire Rescue Department developed and tested a series of simulation techniques for disaster exercises and training purposes.[33] Authors, Peter Kincaid, Joseph Donovan, and Beth Pettitt, noted the advantages of simulators and identified that using simulations resulted in substantially higher training effectiveness when compared to traditional training programs. The program is in its seventh year and has concentrated on emergency management incident command and emergency medical care. The studies could use more work in the area of "modern fire behavior." The U.S. Army used a war game simulation to practice civilian emergency management; the Combat Trauma Patient Simulator used a realistic medical simulator connected to the Internet to model battlefield injuries and casualties.[34]

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[32] Fatimah Lateef, *Simulation-based learning: Just like the real thing*, Journal of Emergencies, Trauma and Shock, 2010;3(4):348-352. doi:10.4103/0974-2700.70743, accessed November 4, 2015.

[33] Peter Kincaid, Joseph Donovan, and Beth Pettitt, *Simulation Techniques for Training Emergency Response*, International Journal of Emergency Management 1, no. 3 (2003): 238–246.

[34] Ibid.

Virtual and gaming environments are no longer considered just a passing trend. Virtual Reality (VR) and online games are quickly growing in popularity and complexity. A wide variety of emergency service personnel and homeland security contingents are leveraging VR systems for training. These include the military, health care, fire service, law enforcement, and more. The Naval Postgraduate School's Modeling, Virtual Environments and Simulation (MOVES) Institute is one example of an organization that develops and study simulations for these disciplines.[35] The faculty members in MOVES Institute work closely with their colleagues from the Operations Research Department and Computer Science Department to combine analysis with simulation, training, and software development. A number of student thesis that were generated as a part of MOVES curriculum serve as great illustration of that work.

Virtual training has proven essential for the military because when faced with combat situations and a variety of operational conditions, the risk is extremely high with very little to no room for error. Troops and leaders need realistic training that challenges their decision making and ability to execute an operation. John Moore, Director of Navy Modeling and Simulation Office, believes that members learn faster and build confidence when they have the opportunity to utilize models and simulation.[36]

The four categories from this literature review—fire behavior, decision making for low frequency and high risk events, training programs for emergency responders, and virtual reality and simulation—can be combined in a unique way to address the gap in training solutions for the fire service. Looking closely at the combined literature in those domains, it can be concluded that there is opportunity for VR and simulation to equip firefighters with experiences that would trigger their recognition-primed decision making when confronted with otherwise low frequency and high risk events involving fire behavior. Perhaps a training program can help decrease line of duty deaths inside burning buildings.

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[35] "MOVES Institute Background," Naval Postgraduate School, https://www.movesinstitute.org/aboutmoves/background/, accessed December 5, 2015.

[36] Amanda D. Stein, "MOVES Highlights Research, Education During Annual Summit," http://www.nps.edu/About/News/MOVES-Highlights-Research-Education-During-Annual-Summit.html, accessed December 5, 2015.

The literature has shown instances where fire is spreading faster and situations becoming more dangerous in smaller operational timeframes than in the past. High-risk situations that are seldom experienced by firefighters have the potential to create a tragic scenario because of the lack of training opportunities. It is important to examine whether these incidents contain sufficient warning signs of imminent catastrophic events present and identifiable to the firefighters and could they (if addressed properly) have a potential to change decision making and avert a tragedy?

III. FIREFIGHTING AND SIMULATION

Firefighters need to be prepared at all times for a variety of situations and have opportunities to practice search and rescue, route navigation, and decision making in critical moments. Simulation has been backed by research as an effective alternative for training because this training method allows personnel to practice dangerous scenarios without damaging equipment, the environment, and most importantly, the physical well-being of those training. Advances in technology have made virtual reality and simulation a viable and attractive option for training in the firefighting domain. The advantages of VR-based fire training simulators will be discussed in this chapter as well as the limitations and possible roadblocks that may be encountered.

A. FIREFIGHTING AND SIMULATION STUDIES

For the Boston Fire Department, the current training method for practicing rescue navigation is for firefighters to train in live-fire conditions in the Academy's burn building. These training scenarios allow firefighters to practice search methods while simultaneously dealing with the heat, smoke, and loud noises of real incidents.[37] While live-fire training at the Academy has many advantages for training the department and providing members with an opportunity to practice decision-making, this training is not sufficient on its own.

The disadvantages of live-fire training are that there is only one burn building, and that coordinating a training scenario uses a significant amount of time and resources. Logistically, a member may only receive this training twice a year. The variety and complexity of fire department rescues and incidents make it unlikely that the training scenario will be similar to an actual incident. At the same time, members are familiar with the layout of the burn building and have an idea of what to expect. The same cannot be said for an event out in the field.

[37] James P. Bliss, Philip D. Tidwell, and Michael A. Guest, "The Effectiveness of Virtual Reality for Administering Spatial Navigation Training to Firefighters," *Presence: Teleoperators and Virtual Environments* 6 (1997): 73–86, accessed September 15, 2016, doi: 10.1162/press.1997.6.1.73.

For these reasons, there is a possibility for the negative transfer of training in which the conditions experienced in the practice building do not match real life scenarios.[38] Finally, a major disadvantage of live-fire training is the threat of physical danger to members in that regardless of experience level, firefighters who train in smoke-filled and high heat conditions face the risk of personal injury.[39]

Firefighters are tasked with entering buildings that they have never been in before and, with visibility either somewhat or severely impaired, they must search for and rescue any trapped occupants.[40] Firefighters cannot wait for fires to occur in order to practice their skills; they need to be prepared at all times for a variety of situations and have opportunity to practice search and rescue, route navigation, and decision making in critical moments. Simulation has been backed by research as an effective alternative for increased training. Even as long ago as 1985, in the article "Human-system performance measurement in training simulators," the authors pointed to simulation as a way to circumvent the problems that come with using actual equipment and environments in the military domain. Simulation allows personnel to practice dangerous scenarios without damaging equipment, the environment, and most importantly, the physical well-being of those training.

In 1997, three researchers recognized the importance of finding new ways to train route navigation due to the complexity and criticality of fire rescue operations.[41] They used a training scenario with thirty-five Madison County, Alabama firefighters and randomly assigned them to three groups: blueprint training, virtual reality training, or the control group of no training. Results of their study demonstrated that the firefighters who were trained with VR or the blueprints performed a faster and more accurate rescue when compared with those without the training. This data supports this thesis in that virtual reality and simulation can provide an effective avenue for firefighting training.

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[38] Ibid.

[39] Ibid.

[40] Donald Vreuls and Richard W. Obermayer, "Human-system performance measurement in training simulators." *Human Factors* 27 (1985): 241–250.

[41] Bliss, Tidwell, and Guest, "The Effectiveness of Virtual Reality for Administering Spatial Navigation Training to Firefighters," 73–86.

B. SIMULATION AND VIRTUAL REALITY—ADVANCES IN TECHNOLOGY

The groundwork for virtual reality and simulation in the firefighting domain started over thirty years ago; however, the technologies have evolved at such a rapid pace in the last decade that makes this training option a viable and attractive one.[42] Computer hardware and software have become an affordable option and capabilities of these programs have improved so quickly that VR is now a feasible option for firefighter training.[43]

Computer-human interaction technology presents users with an opportunity to actively participate in a virtual world and VR-based training simulators can present planned training scenarios in a safe and convenient environment that, most importantly, allows for repetitive operations.[44] Firefighters using these VR-based simulators can find themselves immersed in a virtual environment and given opportunities for interaction through a variety of devices including Head-Mounted Display (HMD), large screens, and trackers.

VR-based fire training simulators give firefighters an experience to make quick decisions and organize their response in a safe environment. An important feature of these simulators, however, is that they can model and present smoke, fire, and heat behavior with realistic graphics. This is possible with the use of computational fluid dynamics (CFD) from the field of engineering to predict and convent the behavior. Researchers have developed a fire training simulator that can calculate invisible physical quantities such as toxic gases and heat as well as visible factors like smoke and flame.[45]

In their study, Moohyun Cha, Soonhung Han, Jaikyung Lee, Byungil Choi proposed a new method to intuitively experience dangerous fire environments and

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[42] Moohyun Cha, Soonhung Han, Jaikyung Lee, and Byungil Choi, “A virtual reality based fire training simulator integrated with fire dynamics data,” *Fire Safety Journal* 50 (2012): 12–24.

[43] Bliss, Tidwell, and Guest, “The Effectiveness of Virtual Reality for Administering Spatial Navigation Training to Firefighters,” 73–86.

[44] Cha, Han, Lee, and Choi, “A virtual reality based fire training simulator integrated with fire dynamics data,” 12–24.

[45] Ibid.

perform training and evaluation. They showed experimentally that the simulator performed to support their framework. The researchers implemented and experimented with their framework to support the performance of the system. The realistic visualization and experience of the data on toxic gases and heat have improved the effects of fire training.

Virtual reality has been used to help fire officers to manage teams to solve incidents that are not possible to train for in real situations. Researchers have used a model that requires the trainee to process and manipulate the physical environment of the physical phenomena and the social environment of the firefighting teams.[46] This virtual environment for fire-fighting training is proposed so that the trainees can learn while doing. The authors have focused on addressing the gap in the way that firefighters use computer techniques for teaching and in the simulation of a crisis by focusing on how the environment is represented and simulated.

C. VIRTUAL REALITY AS EFFECTIVE TRAINING TOOL

Researchers have studied participants' response to a fire emergency in a virtual environment and examined their response patterns and capability of adapting to the situation. A virtual environment was built for participants to explore the environment and then find a quick escape from a fire that they were not expecting.[47] In the study, researchers investigated changes to the intensity of the fire and distances to an exit in order to examine differing levels of danger and difficulty in escaping. Each activation of the interaction device (a triple button joystick) was collected for quantitative analysis and the movements were recorded for qualitative analysis. The conclusion was made that virtual environments are suitable for emergency simulation and an effective training tool because participants recognize a dangerous situation in a virtual environment and readily respond. The validity of virtual environment training was confirmed as an option for both

[46] Ronan Querrec, Cedric Buche, Eric Maffre, and Pierre Chevaillier, "Multiagents systems for virtual environment for training. Application to Fire-fighting," *International Journal of Computers and Applications* 1 (2004): 25–34.

[47] Luciano Gamberini, Paolo Francesco Cottone, Anna Pagnolli, Diego Varotto, and Guiseooe Mantovani, "Responding to a fire emergency in a virtual environment: different patterns of action for different situations," *Ergonomics* 46 (2003): 842–858.

research and training. The study showed how a virtual environment could simulate an emergency scenario and the participants chose adaptive responses to the situations, similar to what would be expected in similar real-life situations.

Full immersive virtual reality has the capability of capturing full body motion, providing a benefit over traditional virtual reality. When participants are fully immersed, they can use their full range of physical motion to interact within the environment and with the computer controlled agents called avatars. Because of this, fully immersive virtual reality provides the opportunity to learn physical activities.

Researchers have shown how participants learned more in an immersive virtual reality system when compared to traditional 2D systems.[48] They gave an example of a system that captures full body motion and shows great promise for firefighters. Full immersion is important to a fire fighter training program because it would allow for body coordination and practicing skills in a manner that is very similar to operational environment. With such a full body system, firefighters could practice their skill sets and be exposed to a wide variety of emergency responses in order to build on their past experience and knowledge for future decision-making.

D. LIMITATIONS OF VIRTUAL REALITY

VR has not addressed the problem of training and navigating (moving) in large virtual environments, and it predominantly relied on gamepads or treadmills to navigate through those environments. In the firefighting domain, this may only present a limitation when the program would like to train on a building of size such as a supermarket or warehouse or in cases of incidents involving a large number of people in a sizable area.[49] In the journal article, "Cognitive Demands of Semi-Natural Virtual Locomotion," the authors explain that a major limitation of VR involves the sensory feedback that a participant receives in a real-world incident. This feedback is often restricted in VR

[48] Kayur Patel, Jeremy N. Bailenson, Sang Hack-Jung, Rosen Diankov, Ruzena Bajcsy, "The Effects of Fully Immersive Virtual Reality on the Learning of Physical Tasks" (paper presented at the annual international workshop on presence, Cleveland, Ohio, August 24–26, 2006).

[49] William E. Marsh, Jonathan W. Kelly, Veronica J. Dark, James H. Oliver, "Cognitive Demands of Semi-Natural Virtual Locomotion," *Presence: Teleoperators and Virtual Environments* 22, no. 3 (2013): 216–234.

because of constraints such as reduced field of view (FOV). The ways in which VR systems have tried to address this limitation has caused the user to use cognitive functions that are not related to the primary task. There is not one VR system that will satisfy all needs of an optimal training environment.

A possibility of negative training when using VR systems also needs to be taken in consideration. Trainees may get used to having more time in scenarios and this could carry over to delayed decision making on the fireground. In order to limit negative training effects, the training environment has to match the operational environment as closely as possible. The training must be tested for the right training capabilities; the skills or knowledge acquired my transfer in a positive way.

Ultimately, the limitation of VR that prevents it from being the one and only training method for fire departments is the fact that there is no replacement for an actual incident. VR is safer, less expensive, and provides a trainee with opportunities to repeatedly practice skills, recognize hazards, and make the best decision for the incident. However, there will never be a replacement for on the job training with real hazards and real people’s lives on the line. That being said, VR can still be considered as important tool in augmenting current training practices.

Despite the possible limitations, VR and simulation is a viable option for training firefighters in search and rescue, route navigation, and critical decision-making. Training in controlled environments allows for firefighters to train on a more frequent basis, improving their abilities to effectively and efficiently mitigate high risk and low frequency events. Data analysis of recent NIOSH line of duty death reports provides a wealth of information to base these training scenarios on.

IV. DATA ANALYSIS

This chapter includes a detailed explanation of NIOSH and their investigations into line of duty deaths in the firefighting domain. A tool was developed using an excel spreadsheet to enable data analysis of the NIOSH LODD reports for the years 2013, 2014, and 2015. The analysis of this data provides us with a basis for a range of recommendations and suggestions on how to address factors that led to catastrophic events—the deaths of firefighters.

A. EXPLANATION OF NIOSH AND REPORTS

The question that this thesis seeks to answer is: During an emergency response to an environment that is immediately dangerous to the life and health of responders, were sufficient warning signs or indicators of imminent catastrophic events present and identifiable to the firefighters, and could they (if addressed properly) have a potential to change decision making and avert a tragedy?

For the purposes of this thesis, a data source was needed in order to study emergency responses associated with low frequency and high risk situations in the firefighting domain. There are approximating 1.1 million firefighters in the United States. The make up of these firefighters includes about 336,000 career firefighters and 812,000 from the volunteer force and each year an average of 80 to 100 die in the line of duty.[50] The Occupational Safety and Health Act of 1970 instituted the National Institute for Occupational Safety and Health (NIOSH) as part of the U.S. Centers for Disease Control and Prevention (CDC) under the U.S. Department of Health and Human Services. NIOSH's mandate is to make sure that every worker in the United States is guaranteed safe and healthy working conditions.[51] In 1998, the problem of work-related firefighter

[50] "Fire Fighter Fatality Investigation and Prevention," Center for Disease Control and Prevention, https://www.cdc.gov/niosh/fire/, accessed April 15, 2017.

[51] "The National Institute for Occupational Safety and Health," Center for Disease Control and Prevention, http://www.cdc.gov/niosh/about/, accessed April 15, 2017.

deaths was recognized as a national issue and Congress funded NIOSH to implement a firefighter safety initiative.[52]

NIOSH recognizes firefighting as a hazardous occupation and conducts independent investigations of firefighter line of duty deaths under the Fire Fighter Fatality Investigation and Prevention program.[53] The goal of this program is to learn from tragic events where firefighters lost their lives with an aim to prevent future similar events. The NIOSH program has investigated approximately 40% of firefighter deaths since it began in 1998, with each fatality investigation prioritized according to the program's decision flow chart.

In this thesis, data analysis of the NIOSH LODD reports was conducted with the goal of identifying possible training deficiencies that may have existed in cases of low-frequency and high-risk events, that, together with other factors, contributed to the line of duty death. The identified training gaps i.e., skills that may have been lacking, were considered as candidates for alternative (and additional) training solutions. The type of cases that we were specifically interested in were the situations where specific skills were identified as lacking, and where current research suggested that computer-supported training solutions were very successful in addressing those skill sets.

It is important to note that NIOSH reports can present limited information as the researcher did not personally design the data collection apparatus, conduct investigations and interviews to guarantee uniformity of approach and unbiased process across all cases; however, the consistency and reputation of NIOSH reports for LODD suggest they are a very valuable tool for analysis and discovery. Indicators and warning signs from actual events where firefighters lost their lives could be used as a guidance to advise the use of additional training solutions, including Virtual Reality (VR) training systems.

One of the questions addressed in this research is: Do the LODD events show sufficient warning signs or indicators that can change decision making and avert a

[52] "Fire Fighter Fatality Investigation and Prevention" Center for Disease Control and Prevention, http://www.cdc.gov/niosh/fire/abouttheprogram/abouttheprogram.html, accessed April 15, 2017.

[53] "Fire Fighter Fatality Investigation and Prevention Program," Center for Disease Control and Prevention, https://www.cdc.gov/niosh/fire/implweb.html, accessed April 15, 2017.

tragedy? Our focus was on situations where firefighters were inside the buildings: they were the victims of burning structure collapse, death caused by extreme fire behavior as well as firefighters being trapped, lost, disoriented, and running out of air. Analysis included data from reports from three years: 2013, 2014 and 2015. Table 1 provides basic information identified in those reports.

Table 1. Number of Reports and Deaths Reported in 2013, 2014 and 2015

Year	# of reports	# of deaths: male	# of deaths: female	Total # of deaths
2013	17	19	1	20
2014	24	25	1	26
2015	16	16	0	16
Total	57	60	2	62

This thesis presents the opportunity to learn from past events and practices, the successes and failures in firefighting domain without the bias of being closely involved with the cases or having a specific agenda. Quantitative analysis and the knowledge gleaned from looking at the events after the fact provide a foundation for advising novel scenarios that can be used to train both individual firefighters and teams on a daily basis. Application for improved and more effective training includes a critical review of indicators gleaned from the data.

B. APPARATUS

An excel spreadsheet was developed as a tool to enable data analysis of the NIOSH line of duty death reports for the years 2013, 2014, and 2015. The analysis of data from the NIOSH reports provides us with a basis for a range of recommendations and suggestions on how to address factors that led to catastrophic events—the deaths of firefighters. The excel spreadsheet tracked the data reported in 57 reports; the information that was derived for each death consisted of following twenty eight elements:

1. Report No.
2. Incident Date
3. Time
4. State
5. Time to Arrival (minutes)
6. Size of City/Town at the time (population)
7. Size of the City/Town Area (square miles)
8. Size of Department
9. # of FF Deaths
10. # of Injured
11. Building Type
12. Arrival Report
13. Recommendations:
    - situational awareness (SA),
    - annual medical eval (AME),
    - annual physical ability eval (APE),
    - wellness and fitness program (WF),
    - exercise stress tests (EST),
    - cleared for duty (CD),
    - accountability system (AS),
    - report unsafe conditions (RUC),
    - work in teams (WT),
    - PASS device (PD),
    - crew integrity (CI),

- air management (AM),
- deployment to charlie side (DC),
- size up (SU),
- risk assessment (RA),
- dispatch comms (COMMS),
- collapse awareness (CA),
- ineffective incident command (IIC),
- driver training (DT),
- SOP for wind (SOPW),
- Modern Fire Behavior (MFB),
- appropriate equipment (AE),
- Mayday training (MT),
- adequate resources (AR)

14. Paid, Volunteer, or Combination Department

15. Cause of Death:

    - aortic dissection (AD),
    - cardiovascular disease (CD),
    - diabetes mellitus (DB),
    - electrocution (EL),
    - fall (FA),
    - lost (LO),
    - myocarditis (MC),
    - myocardial infarction (MI),
    - smoke inhalation (SI),

- trapped (TR),
- victim of collapse (VC),
- motor vehicle (MV)

16. Gender [Male/Female]
17. Age
18. Rank
19. Years on Job
20. Training/Certs
21. Duty:
    - advance line interior (ALI),
    - advance line exterior (ALE),
    - emergency medical services (EMS),
    - investigating (IN),
    - motor vehicle accident (MVA),
    - rapid intervention (RI),
    - search & rescue (SR),
    - safety officer (SO),
    - technical rescue (TEC),
    - training (TR),
    - ventilation (VE)
22. Interior/Exterior [I/E]
23. Wearing SCBA [Y/N], unclear [U]
24. AlarmsLocation specifics
25. Condition under which death occurred:

- air management (AM),
- arson (AR),
- ammunition sounding (AS),
- construction features (CF),
- crew integrity (CI),
- delayed notification (DN),
- extreme heat (EH),
- elevators inoperable (EI),
- electrical hazards (EL),
- external structures hazards (ESH),
- failure to call Mayday (FM),
- flashover (FO),
- failure to fully open SCBA (FS),
- fire in void space (FV),
- hoarder (HO),
- lack of accountability (LA),
- lack of experience (LE),
- lack of water supply (LWS),
- miscommunication with dispatch (MD),
- failure to wear seat belt (NSB),
- companies delayed/ out of service (OOS),
- pre-existing hazardous structure (PHS),
- poor ventilation (PV),
- rapid fire behavior (RFB),

- secondary collapse (SC),
- standard op procedures training (SOP),
- temperature inversion (TI),
- unrestricted flow path (UFP),
- unreported hazard (UH),
- underlying medical conditions (UMC),
- working alone (WA),
- weather conditions (WC),
- wind speed (WS)

C. RESULTS FROM THE DATA—INDICATORS

The analysis of NIOSH reports done for this thesis included data from the years 2013–2015. The National Fire Protection Association (NFPA) has studied and conducted data analysis on NIOSH reports; however, the last published source from the NFPA concluded in the year 2009. To the best of our knowledge this thesis represents the first effort to analyze reports from recent years. The significance of this work is also in the fact that the literature has demonstrated the changing nature of the firefighting profession. Scientists from UL and NIST compared the contents of present day homes to “legacy” homes from the 1950s to 1970s and coined the term “modern fire behavior” to define the rapid speed and intensity of modern day fires.[54] Researchers suggest that these changes are due to a number of factors including the cumulative effect of larger homes, open house geometries, synthetic materials, and modern construction practices.[55] UL and NIST research demonstrates that firefighters can no longer rely on past practices and traditional tactics of previous generations to inform their knowledge of fire behavior and decision making on the fire-ground.

[54] Underwriters Laboratory, “House fire furnishing comparison.”

[55] Underwriters Laboratory, “Modern Residential Fires.”

As reported in Table 1 a total of 57 reports were analyzed with a total number of line of duty deaths being 62. Table 2 provides analysis of all deaths by causes that were identified in reports. The highest number of deaths reported was caused by cardiovascular disease (CD) and myocardial infarction (MI), the majority of them caused by the condition of physical exertion leading to a cardiac event (PEC). “CD only” caused 14 deaths (22.58% of all deaths); 12 of these were older than 40 years. “MI only” caused 12 deaths (19.35%); 10 of these were older than 40 years. Some of these reports included causes of death that had a number of named causes contributing to the loss. For example, Cardiovascular Disease was paired with myocardial infarction (MI) and diabetes mellitus (DB). Aortic dissection and myocarditis were other underlying medical conditions leading to death.

Table 2. Number of Deaths by Causes

Cause of deaths	#	% of total deaths	Min age	Max age	Average age	# of older than 40
AD only	1	1.61	41	41	41	1
CD only	14	22.58	37	62	50	12
EL only	1	1.61	36	36	36	0
FA only	3	4.84	42	54	47	3
LO	0	N/A	N/A	N/A	N/A	N/A
MC only	0	N/A	N/A	N/A	N/A	N/A
MI only	12	19.35	22	63	52	10
MV only	1	1.61	28	28	28	0
TR only	4	6.45	33	43	38	1
SI only	2	3.23	19	48	34	1
VC only	8	12.90	24	51	38	4
Multiple causes	7	11.29	35	60	49	5
Missing info	9	14.52	37	54	46	6
Total	**62**	**100.00**	**19**	**65**	**46**	**43**

Aortic dissection (AD), cardiovascular disease (CD), diabetes mellitus (DB), electrocution (EL), fall (FA), Lost (LO), myocarditis (MC), myocardial infarction (MI), smoke inhalation (SI), trapped (TR), victim of collapse (VC), motor vehicle (MV).

The aim of this thesis was to focus on cases where firefighters lost their lives as a result of operating inside burning buildings, and identify the warning signs and indicators identified in those cases, for training purposes. The goal was to learn from incidents where firefighters were victims of burning structure collapse, death caused by extreme fire behavior as well as firefighters being trapped, lost, disoriented, and running out of air. The NIOSH reports from 2013–2015 did present data on these types of incidents; however, the number of reports involving physical exertion leading to cardiac events was overwhelming and could not be ignored because they have the potential to present important information and help generate advice for possible training solutions that could be used to address those skill gaps (some of those training solutions may also be virtual reality training systems.)

The *duties* being performed while these deaths occurred varied and did not appear to have significant connection to the causes of death (Table 3). However, what the data did show is that advancing a line in the interior of a building caused the highest number of deaths: advancing the interior line was a duty in 14 cases of death, and search and rescue was the second most hazardous duty in seven of the death reports. Surprisingly, seven deaths occurred during training exercises. Other types of duties where firefighters lost their lives included while investigating incidents (4), driving an apparatus (2), conducting emergency medical services (1), and performing technical rescue (1).

Table 3. Number of Deaths by Type of Duty Performed at the Time of Death

Duty	#	% of total deaths	Min age	Max age	Average age	# of older than 40
ALE only	4	6.45	52	58	55	4
ALI only	14	22.58	19	57	39	7
EMS only	1	1.61	59	59	59	1
IN only	3	4.84	36	57	47	2
MVA only	2	3.23	28	40	34	0
OH only	1	1.61	50	50	50	1
RI only	0	0.00	N/A	N/A	N/A	N/A
SO only	1	1.61	62	62	62	1
SR only	7	11.29	40	62	49	6
TEC only	1	1.61	28	28	28	0
TR only	7	11.29	48	63	56	7
VE only	0	0.00	N/A	N/A	N/A	N/A
Missing info	20	32.26	22	65	44	13
Multiple duties	1	1.61	46	46	46	1
Total	**62**	**100.00**	**19**	**65**	**46**	**43**

Advance line interior (ALI), advance line exterior (ALE), emergency medical services (EMS), investigating (IN), motor vehicle accident (MVA), rapid intervention (RI), search & rescue (SR), safety officer (SO), technical rescue (TEC), training (TR), ventilation (VE).

Another factor examined in the NIOSH reports were *condition under which death occurred*. In the 62 reported deaths that happened between 2013–2015, half of the deaths (31) occurred as physical exertion leading to a cardiac event (one additional death was caused by a combination of physical exertion leading to a cardiac event and smoke inhalation) (Table 4). This was mentioned earlier and should be stressed again as a necessary focus for designing a training program (simulation or otherwise) to help firefighters realize the dangers of not maintaining their bodies and participating in a fitness and wellness program. The next leading causes of death were victim of collapse (8 deaths), smoke inhalation and falls (3 deaths each), and sudden cardiac death (2 deaths). Becoming trapped, motor vehicle accidents and water rescue caused 1 death each.

Other conditions on the fire ground that should signal firefighters for careful decision making include collapse potential and smoke inhalation. At the same time, there were very rare incidents that cause tragic accidents including electrocution, traffic incidents, and a water rescue. Innovative training programs should focus on the events that are occurring most often; however, firefighters need to be aware of the rare events that are low frequency yet high risk and could cause a tragic death.

Table 4. Condition under which Death Occurred

Condition	#	% of total deaths	Min age	Max age	Average age	# of older than 40
BU only	0	0.00	N/A	N/A	N/A	N/A
CO only	8	12.90	24	51	38	4
EH only	0	0.00	N/A	N/A	N/A	N/A
EL only	1	1.61	36	36	36	0
FA only	3	4.84	42	54	47	3
FB only	0	0.00	N/A	N/A	N/A	N/A
HE only	0	0.00	N/A	N/A	N/A	N/A
LO only	0	0.00	N/A	N/A	N/A	N/A
NSB only	0	0.00	N/A	N/A	N/A	N/A
PEC only	31	50.00	22	63	49	24
SCD only	2	3.22	49	65	57	2
SI only	3	4.84	19	48	38	2
TI only	0	0.00	N/A	N/A	N/A	N/A
TR only	1	1.61	37	37	37	0
WR only	1	1.61	46	46	46	1
Missing info	3	4.84	49	60	54	3
Multiple conditions	9	14.52	28	62	41	4
Total	**62**	**100.00**	**19**	**65**	**46**	**43**

Burns (BU), collapse (CO), extreme heat (EH), electrocution (EL), fall (FA), fire behavior (FB), heat exhaustion (HE), lack of oxigen (LO), no seat belt (NSB), physical exertion leading to cardiac event (PEC), sudden cardiac death (SCD), smoke inhalation (SI), traffic incident (TI), trapped (TR), water rescue (WR).

Another source of analysis for the reports was *indicators* surrounding the circumstances of the death Table 5). “Underlying medical conditions” were named as the sole indicator in 28 deaths. In the rest of the reports where indicators were named, there were a number of indicators from two to up to nine that could have signaled warning of an impending tragedy. In 12 of the cases, an unreported hazard was a major factor in the line of duty death. In many of these cases, firefighters recognized a hazard but did not report to the incident commander so that the remaining members on the fireground would be made aware of the danger. This is an area that can present valuable information for training purposes. Members need to repeatedly practice recognizing and reporting hazards so that they feel comfortable making these announcements on the fireground. Some firefighters might assume that it is up to an officer or a chief to report these dangers; however, it is necessary to develops the culture and habit that if one sees something dangerous, that person will report it immediately. Possibly, this can prevent future tragedies. Crew integrity was another common *indicator*. In seven of the cases, members were separated from each other and a lack of accountability led to a line of duty death.

Table 5. Indicators Surrounding the Circumstances of the Death

Indicator	#	% of total deaths	Min age	Max age	Average age	# of older than 40
UMC	28	45.16	22	63	51	24
Missing info	9	14.52	30	65	46	6
Multiple indicators	25	40.32	19	62	40	13
Total	**62**	**100.00**	**19**	**65**	**46**	**43**

Air management (AM), arson (AR), ammunition sounding (AS), construction features (CF), crew integrity (CI), delayed notification (DN), extreme heat (EH), elevators inoperable (EI), electrical hazards (EL), external structures hazards (ESH), failure to call Mayday (FM), flashover (FO), failure to fully open SCBA (FS), fire in void space (FV), hoarder (HO), lack of accountability (LA), lack of experience (LE), lack of water supply (LWS), miscommunication with dispatch (MD), failure to wear seat belt (NSB), companies delayed/ out of service (OOS), pre-existing hazardous structure (PHS), poor ventilation (PV), rapid fire behavior (RFB), secondary collapse (SC), standard op procedures training (SOP), temperature inversion (TI), unrestricted flow path (UFP), unreported hazard (UH), underlying medical conditions (UMC), working alone (WA), weather conditions (WC), wind speed (WS).

For the majority of the reports, a wide variety and combination of indicators were named in the reports. Although no specific pattern emerged, the indicators named in the analysis and the variety of ways they combined to create a deadly situation provide valuable information that helps design innovative training scenarios. From the more common problems of pre-existing hazardous structures to the rare events of temperature inversion creating a dangerous environment, each report gave valuable information for indicators that firefighters can and should become familiar with.

In 19 of the cases, situational awareness was named as a key recommendation. This was often paired with an accountability system, size up, and conducting an adequate risk assessment for decision making. Other recommendations that can be incorporated into training scenarios include air management, deployment to the Charlie side (back of the building), dispatch communications, collapse awareness, modern fire behavior, Mayday training, and an increased knowledge of fires involving wind conditions.

The analysis of data that were derived from NIOSH reports provides us with a basis for a range of recommendations and suggestions on how to address factors that led to catastrophic event— the deaths of firefighters. In cases where physical exertion led to a cardiac event, the departments should develop annual medical evaluation and annual physical ability evaluations for their members. A preventative wellness and fitness program for all members has the potential to decrease these line of duty deaths. Exercise stress tests and ensuring that injured members are cleared for duty before returning to work are strongly recommended measures suggested by the committees conducting the NIOSH investigations.

D. DATA-DRIVEN TRAINING PROGRAM

The NIOSH reports where firefighters lost their lives inside burning buildings, provide a great degree of information for designing simulation-based training scenarios. These reports include actual, real-life incidents, where families lost loved ones and we owe it to these fallen heroes to learn from the events and prevent similar scenarios from occurring again. The circumstances surrounding a LODD are extremely complex and the

purpose of this thesis is not to place blame but instead to learn from tragedy to prevent it in the future.

Sixty-two reports from the past three years were analyzed. Of these line of duty death reports, thirty-three of them described a harrowing similar situation where the condition under which the death occurred as physical exertion leading to a cardiac event. The theme in these reports was that the victim had underlying medical conditions. The variety of causes of death included myocardial infarction, cardiovascular disease, myocarditis, diabetes mellitus, and aortic dissection.

Recommendations from the NIOSH reports on these types of line of duty deaths include the need for annual medical evaluations, annual physical ability evaluations, a wellness and fitness program, exercise stress tests, and the importance of being cleared for duty by a medical doctor before returning to work. Fire Departments need adequate resources to establish these types of programs. For Fire Departments who do have the recommended programs in place and the resources of a department doctor, there still may be hesitancy to schedule annual medical evaluations and participate in a wellness and fitness program. With half of the reports demonstrating the frequency in which physical exertion led to cardiac events, perhaps a simulation highlighting the importance of members participating in a wellness and fitness program could influence members and help them recognize that their life could depend on whether or not they address any underlying medical conditions.

The remaining thirty reports presented a wealth of information with indicators that could be used to design scenarios that depict situations in which there would be high likelihood of losing firefighters in the line of duty. Three major categories from the indicators where firefighters need repetitive training include basement fires, high-rise fires, and wind-driven fires.

Simulation could help firefighters practice these types of fires and recognize the dangers of a basement fire and the limited egress capabilities should fire cut off an escape route. Practicing a high-rise fire can train firefighters to close doors and isolate fire as well as enforce the teamwork necessary to stretch and place a hose line in position. The

potential for a wind-driven fire can be recognized prior to the incident taking place when firefighters recognize a high wind speed during a work shift. Members need opportunities to recognize indicators during all aspects of sizing up a fire throughout the incident.

There are also rare scenarios that were identified while analyzing the NIOSH reports, that, if incorporated into a simulation training program, could help a firefighter improve decision making for low-frequency events that may catch him (her) off guard. Firefighters have lost their lives in events that involved rarely seen circumstances. These incidents include an event where the differential pressure during a water rescue created a hazardous area and incidents when temperature inversion created deadly situations.

Firefighters need to be trained on the unexpected because in the chaos of a fire, anything is possible. A simulation can challenge a firefighter in how he/she would respond in the following rare events found in the NIOSH reports:

1. Members hear ammunition sounding.
2. The 3-family house with a fire on the second floor that has an extreme hoarding problem.
3. An arsonist has started several fires in an area and a fully-involved building has the possibility of being fueled by flammable liquids.
4. Temperature inversion.
5. Elevator inoperable.

There are also instances in which circumstances that could initially be taken as inconsequential, have instead caused devastating results. Simulation can help firefighters recognize these indicators with practice and realize that they could be the difference between life and death at a fire. Examples include following situations:

1. Delayed companies.
2. Miscommunication with dispatch.
3. Pre-existing hazardous structures.

A common problem in LODD reports was the fact that hazards went unreported. Firefighters need practice recognizing and giving verbal reports on the radio to everyone

on the fireground of the hazards that they recognize. All members are responsible to make these reports and a sense of complacency can prevent members from taking this preventative action. Firefighters need to be aware and know how to act on the responsibility of reporting hazards. The more firefighters are able to practice the skill of reporting hazards, the more likely that it will become second nature during a fire response. Along these same lines, firefighters also need training opportunities to practice calling maydays and the subsequent steps that need to be taken after a mayday is called.

Deceptive initial reports of “nothing showing” can become especially dangerous for firefighters. Modern fire behavior and rapid fire growth can cause a situation that appears harmless to turn deadly in a matter of minutes. Simulation would teach firefighters to never take an incident for granted and to prepare for the unexpected. This can also be applied to electrical hazards, that if not taken seriously, can cause death. Firefighters can be trained through simulation to look for and expect fire in void spaces and be prepared for the possibility of unrestricted flow paths that have cut off escape routes and trapped firefighters.

A training program designed around the indicators from the NIOSH reports can increase awareness and improve firefighter awareness in identifying and averting line of duty deaths and injuries. Simulation and VR would provide the opportunity to build a different kind of education, one that can provide repetitive training to build recognition-primed decision-making skills of firefighters. This type of real-time, scenario-driven training systems will represent education that is different from traditional classroom approach; it will be safer than live-fire while giving firefighters the opportunity to build their skills and increase their experiences.

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V. CONCLUSIONS AND RECOMMENDATIONS

Firefighters must put themselves in dangerous and unpredictable situations. Training and preparedness equips firefighters with the ability to mitigate many different hazardous events and incidents. A training program designed around the indicators from the NIOSH reports can improve firefighter awareness in identifying and averting line of duty deaths and injuries. Simulation and virtual reality is a viable training avenue to provide repetitive training and build recognition-primed decision-making skills of firefighters. In this final chapter, the reasons why the firefighting domain needs virtual reality training will be discussed as well as the limitations of this thesis and recommendations for future research.

A. WHY WE NEED VIRTUAL REALITY TRAINING

A firefighters shift is unpredictable and the inability to determine the timing and nature of the stressful alarms and situations can bring about psychological stressors, making fire fighters at risk for depression and posttraumatic stress disorder.[56]

> Firefighting is among the most strenuous occupations during periods of peak activity. These peaks punctuate long periods of inactivity or waiting in readiness and are often announced by stressful alarms. Psychological stresses related to the firefighter's considerable responsibilities for life and property add to the demands on the firefighter in action…. firefighting places maximal demands on the individual firefighter.[57]

Firefighters are required to go toward danger when others are running away; they must put themselves in situations with degrees of danger that have the possibility of being unpredictable. The more training and preparedness that an individual has, the more prepared he (she) will be to deal with hazardous events and incidents that are immediately dangerous to their life.

[56] Tee L. Guidotti, "Human factors in firefighting: ergonomic-, cardiopulmonary-, and psychogenic stress-related issues," *International Archives of Occupational and Environmental Health* 64, no. 1 (1992): pp. 1–12.

[57] Ibid.

A training program designed around the indicators from the NIOSH reports can increase awareness and improve firefighter awareness in identifying and averting line of duty deaths and injuries. Simulation and virtual reality would provide the opportunity to build a different kind of education, one that can provide repetitive training to build recognition-primed decision-making skills of firefighters. This will include a different kind of education than classroom only and safer than live-fire, giving firefighters the opportunity to build their senses and increase their experiences.

Today's firefighters must find ways to improve their training for the hazards associated with emergency responses that fall in the category of low-frequency events that pose a high-risk to responders, civilians, and the environment. When first responders are faced with events that rarely occur, they may lack these past experiences that will help them make good decisions. An effective and well-designed training program is a possible solution that could fill in the gap for developing recognition-primed decision-making skills for these low-frequency and high-risk incidents.

Since 1977, the number of structure fires each year has declined by 52 percent.[58] This finding points to the fact that today's firefighters have less of an opportunity to train on the job than the older and retired members of departments. For this reason, the argument can be made that responding to a building fire with the need for an aggressive interior attack has become a low frequency and high risk event. Simulation will present the opportunity to train on the scenarios from NIOSH reports, focusing on understanding the indicators that have led to line of duty deaths in the past.

In some cases, VR may provide the only way to train safely. Training that makes use of simulations provides an option for situations when access to other training opportunities may be prohibited. For example, new firefighters who are not yet ready to be out in the hostile environment or at the other extreme, in cases of radiation, VR is the only safe way to train. It becomes apparent under these circumstances that we need VR systems. The question then becomes, what system will best suit the training scenario?

[58] Fahy, "US Fire Service fatalities in structure fires, 1977–2009," 1–9.

For simple training, the screen and mouse of a desktop or laptop computer can run a trainee through a scenario. More complex systems include immersive VR where the entire field of view of a human operator is being captured by the simulated visuals that are presented inside the headset with no visual information coming from the real world in which operator exist.

Contrary to VR, in AR, there is a full recognition of the real world. The visual information from the real world can be enriched with synthetic events to provide the trainees with a different type of situation than if they saw only the real world. For example, one could see a real building with added simulated sensory information to enrich that experience.

There is a variety of reasons why training solutions that harness VR technology have been endorsed and used in a number of domains like military domain, training of medical personnel and industry. A major reason to rely on VR has been in its potential to save resources, providing an alternative environment for practice. Resources that could be saved include staffing, organizing, logistics, transporting, fuel, maintenance, parts, etc. VR can also provide training when there are no other options available. Any domain could be scrutinized to identify the things and situations that could not be supported otherwise. In some cases, it would even focus on need to run through a large number of training scenarios in short period of time. To do that effectively it would be necessary to establish a training regimen and a model for decision-making practice, and create challenging training scenarios that will support that practice.

B. LIMITATIONS OF THE STUDY

How do we address the problem of handling and operating in new situations? For a force trained with traditional tactics, how do we train for new situations and environments and what is the best way to train? These are questions that need to be asked and studied in future research efforts. There are certain skills that can help master the operational environments, and situations where VR may not provide a benefit. The effectiveness of each training approach and possibly even scenario needs to be tested.

Another limitation of the study is the fact that a line of duty death is almost never the result of a single item or one wrong decision. Instead, it is a complex situation that involves contribution of many factors. This research began with the hope to pinpoint exact elements that would help design future training. Several themes surfaced as a result of data analysis, and a variety of different situations identified in NIOSH reports demonstrated the need for a training system that is just as complex and varied as real life situations. Any efforts invested towards reducing and in ideal case eliminating the number of injuries and deaths on the fire ground, should be welcomed.

It is important to remark that this study did not include reports where firefighters were injured or "near-miss" incidents. NIOSH only conduct their detailed reports on the line of duty deaths and even then, not all cases are investigated. They use their flow chart to determine when to form a committee and begin an investigation. Because of this, not all available data is collected and a vast majority of knowledge from injury reports is missed out on.

C. RECOMMENDATIONS AND FUTURE WORK

The indicators identified in the study can be used to project training needs, scenarios, cost, and other considerations commonly treated in the literature. Questions to ask for future research include whether or not the training would be realistic enough. Is it possible to train the volume of firefighters currently in an urban fire department? Are there urban departments that rely on simulation training scenarios for their programs?

Further research should also be directed towards study of injuries on the job with attention to questions such as: What types of situations cause the most injuries? Do repeated injuries occur to a certain demographic? What type of situation causes injuries of a certain kind? What is the training level and time of a firefighter who gets injured?

Research into NIOSH line of duty death reports was time-consuming as each report had a great deal of detail in it. The time to publish a report after an incident can sometimes take years and in the meantime, similar incidents can occur in different parts of the country. It would benefit the fire service if NIOSH could release short summary reports of the LODD, highlighting the major circumstances surrounding the incident.

This practice would warn firefighters of the current dangers in the field as soon as possible after a tragic death.

This thesis demonstrates the need for more researchers to ask questions and join the fire service in brainstorming alternative ways of training of firefighters. The hope is that individual departments will realize the need for accurate record keeping and sharing of information across the country. Data collected from departments could be combined to come up with an overall understanding of issues that are causing injuries and deaths. A collaborative effort to create and implement changes in training can save many lives in the fire service.

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